Journal of Dental Sciences (2011) 6, 200–204

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ORIGINAL ARTICLE

Pullout strengths of orthodontic palatal mini-implants tested *in vitro*

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Received 11 August 2011; accepted 3 October 2011
Available online 28 October 2011

KEYWORDS
insertion torque;
palatal mini-implant;
pullout strength;
skeletal anchorage

Abstract *Background/purpose:* New modified mini-implants are used in orthodontic practice to reinforce palatal anchorage. The aim of this study was to evaluate the anchorage strengths of palatal mini-implants in terms of their vertical and horizontal pullout strengths.
Materials and methods: Thirty palatal mini-implants (2 mm in diameter) of three brands (Absoanchor, Bio-Ray, and Lomas) were manually driven into artificial bone (Sawbones) to a depth of 5 mm. Their vertical and horizontal pullout strengths were measured using a material testing machine. The Kruskal–Wallis test was used to assess differences among brands ($P < 0.05$).
Results: The pullout strengths of all the brands were significantly greater than routine orthodontic forces. The vertical pullout strength of the Absoanchor mini-implants was the lowest among the tested brands, and the horizontal pullout strengths of the Lomas and Absoanchor mini-implants were significantly higher than that of the Bio-Ray mini-implant. There was no significant relationship between the insertion torque and pullout strength in the vertical or horizontal directions.
Conclusion: The pullout strengths of mini-implants were significantly greater than normal orthodontic forces. Moreover, no significant correlation was found between the insertion torque and pullout strength.

Introduction

Steady anchorage is very important for successful orthodontic treatment. Limited intraoral anchorage and acceptance problems associated with extraoral appliances often

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1991-7902/$36
doi:10.1016/j.jds.2011.09.003

lead to anchorage loss, which impedes orthodontic treatment. In the 1960s, Brånemark et al introduced the use of titanium implants. Decades later, these implants have achieved a success rate of >90%.[1–3] Dental implants are a reliable and popular treatment option for oral rehabilitation, and their use in reinforcing orthodontic anchorage has shown encouraging results.[4,5] In 1996, Wehrbein et al[6] introduced the concept of using a palatal implant as a source of anchorage. Many studies[7–9] demonstrated that palatal implants are a suitable alternative to extraoral anchorage. However, most palatal implants require flap operations for insertion and removal because of their large diameters (≥3 mm).

Recently, smaller diameter (2 mm) implants were developed for skeletal anchorage in orthodontic treatment, eliminating the need for a flap operation. However, the pullout strengths of palatal mini-implants have never been assessed. The aim of our study was to evaluate the anchorage strengths of palatal mini-implants in terms of their vertical and horizontal pullout strengths.

Figure 2 The Bio-Ray (2.0 × 8 mm) was inserted into the anterior palatal region.

Materials and methods

We evaluated 30 mini-implants (2 mm in diameter) of three brands (Fig. 1). Ten mini-implants per brand were equally divided to test vertical and horizontal pullout strengths. The lengths of Absoanchor (8 mm; Dentos inc., Taegu, Korea) and Bio-Ray (8 mm; Bio-Ray Biotech, Taipei, Taiwan) mini-implants were even numbers, whereas that of Lomas (7 mm; Mondeal, Tuttlingen, Germany) mini-implants was an odd number. The thickness of the anterior palatal mucosa is approximately 2–3 mm (Fig. 2). Both Absoanchor and Bio-Ray mini-implants have a 3-mm mucosal thickness, whereas Lomas mini-implants have a 2-mm mucosal thickness because of their odd-numbered length.

Instead of animal bone, artificial bone (Sawbones, Pacific Research Laboratories, Vashon, WA, USA) was used for the experiments (Fig. 3). The overall uniformity and consistent physical properties of Sawbones make it a suitable material for comparative testing of mini-implants. Kim et al[10] used 30 pcf (0.48 g/cm^3) Sawbones (solid rigid polyurethane foam) to compare the stability of cylindrical and conical mini-implants. To simulate palatal bone, we attached a 40 pcf (0.64 g/cm^3) cellular rigid polyurethane sheet (cortical bone; 2 mm thick) to a 20 pcf (0.32 g/cm^3) block (cancellous bone; 20 mm thick) with an acrylate bond (Scotch, 3M, St. Paul, MN, USA). A custom-fabricated clamping apparatus was used to hold the artificial bone. The mini-implants were placed perpendicular to the artificial bone and then self-drilled to a depth of 5 mm into the bone.

The insertion torque was measured with a digital torque meter (Lutron, Taipei, Taiwan) (Fig. 4). Vertical (Fig. 5A) and horizontal (Fig. 5B) pullout tests were performed using a material testing machine (Lloyd, Berwyn, PA, USA). An orthodontic wire (0.018 inch) was passed through the hole of the implant and then tied to the pulling apparatus. Five power chains (Ormco, Glendora, CA, USA) were also used to estimate the peak breaking force (Fig. 6). An optical measuring projector (Starrett, MA, USA) was used to measure the dimensions of the mini-implants (Fig. 7).

The Kruskal–Wallis test was used to evaluate differences among the implant types. Statistical significance was

Figure 1 From left to right: Bio-Ray (2.0 × 8 mm), Absoanchor (2.0 × 8 mm), and Lomas (2.0 × 7 mm).

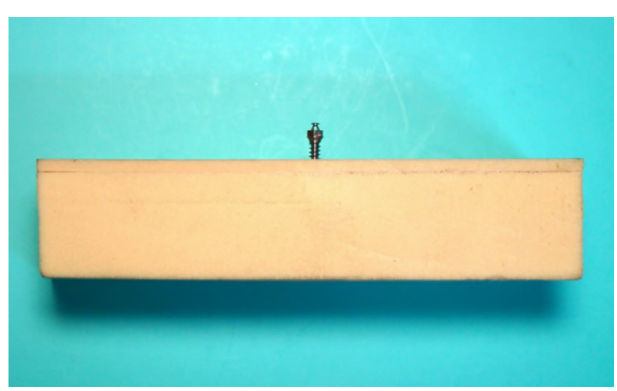

Figure 3 The thickness of anterior palatal mucosa was designed as 3 mm and an Absoanchor (2.0 × 8 mm) was self-drill inserted into the Sawbones (cortical bone: 2 mm thickness; cancellous bone: 20 mm thickness) with 5 mm depth.

Figure 4 The digital torque meter (Lutron).

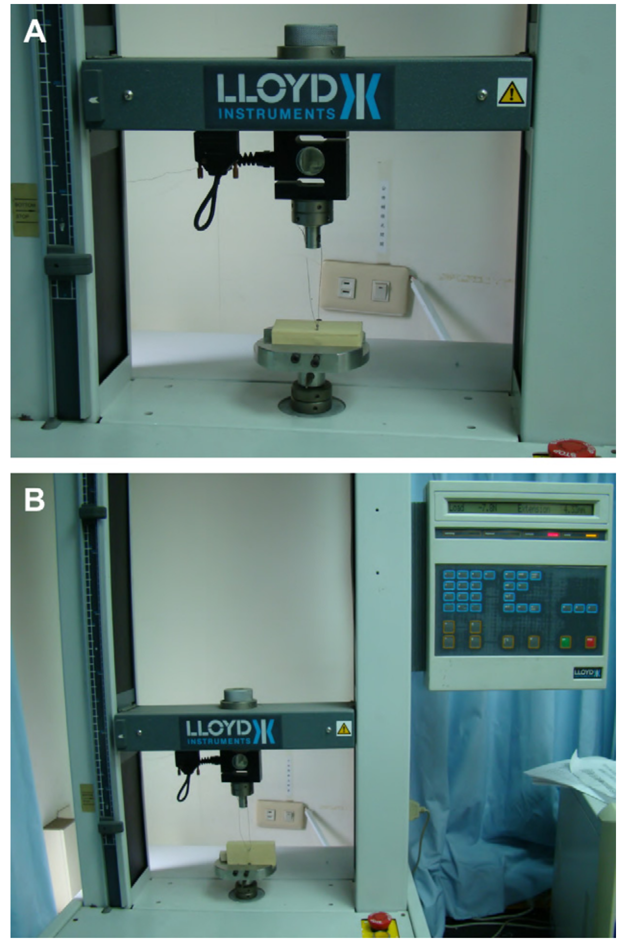

Figure 5 An orthodontic wire (0.018 inch) was passed through the hole of the mini-implant and the n tied into the material testing machine (Lloyd). (A) Vertical pullout test; (B) horizontal pullout test.

set at $P < 0.05$. The Pearson correlation coefficient was used to predict the relationship between the insertion torque and pullout strength for all mini-implants.

Results

The parameters of the mini-implants and average breaking force of the power chains are shown in Table 1. The ratio of the inner to the outer diameter of the Absoanchor (0.64) mini-implants was smaller than those of the Bio-Ray (0.78) and Lomas (0.73) mini-implants. Furthermore, the thread depth of the Absoanchor (0.35 mm) mini-implants was greater than those of the Bio-Ray (0.22 mm) and Lomas (0.27 mm) mini-implants. The mean peak breaking force of the power chains was 21.9 N/cm.

The vertical insertion torques and pullout strengths of the mini-implants are shown in Table 2. The insertion torque was greater for the Lomas (10.82 N/cm) mini-implant than for the Bio-Ray (8.62 N/cm) and Absoanchor (6.2 N/cm) mini-implants, but no significant difference was noted among the brands. The vertical pullout strength of each brand was measured in five experiments (Table 2). The Lomas (139.68 N/cm) mini-implants exhibited a greater vertical pullout strength than did the Bio-Ray (133.14 N/cm) and Absoanchor (109.72 N/cm) mini-implants, but that of the Absoanchor mini-implant was significantly lower than those of the other brands. No significant correlation was found between the insertion torque and vertical pullout strength of any brand.

The horizontal pullout strength of each mini-implant was measured in five experiments (Table 3). Again, the insertion torque was greater for the Lomas (11.66 N/cm) mini-implant than for the Bio-Ray (9.74 N/cm) and Absoanchor

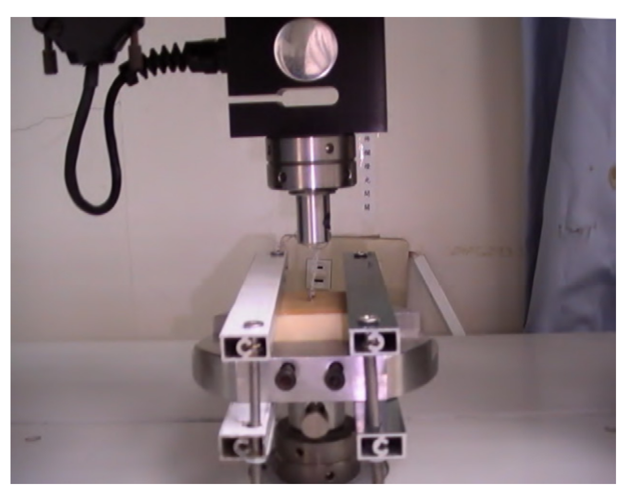

Figure 6 Power chain was tested for breaking force.

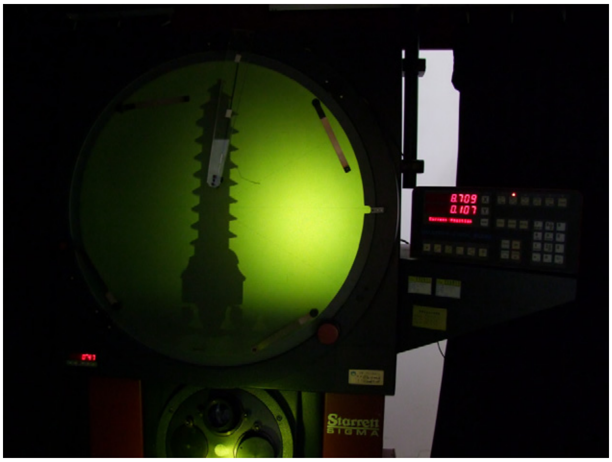

Figure 7 An optical measuring projector (Starrett) projects the dimension of the Absoanchor mini-implant.

(5.9 N/cm) mini-implants, and the horizontal pullout strength (179.78 N/cm) of the Lomas mini-implant was greater than those of the Absoanchor (171.62 N/cm) and Bio-Ray (124.84 N/cm) mini-implants. The Lomas and Absoanchor mini-implants had significantly greater horizontal pullout strengths than did the Bio-Ray mini-implant. However, there was no significant difference in pullout strengths between the Lomas and Absoanchor mini-implants. Furthermore, no significant correlation was found between the insertion torque and horizontal pullout strength of any brand.

Discussion

Anchorage control is a fundamental aspect of orthodontic treatment. Osseointegrated implants provide reliable anchorage. By comparing the effectiveness of palatal implants and headgear, Sandler et al[11] found that palatal implants are acceptable for reinforcing anchorage in patients undergoing orthodontic treatment and a suitable alternative for those who do not wish to wear headgear. Furthermore, Feldmann and Bondemark[12] reported that palatal implants have significantly higher success rates for anchorage than do headgear and transpalatal bars. Palatal implants (Straumann, Basel, Switzerland) have a >90% success rate,[9,13] which is similar to that of dental implants for prostheses. Patients often prefer to commence their palatal implant-based orthodontic treatment as soon as possible. Therefore, the stability of immediate loading is very important. When comparing stabilities, Jackson et al[14] showed that delayed loaded palatal implants have significantly greater stability than immediately loaded palatal implants. We agree with their findings and perform delayed loading of palatal implants for up to 3 weeks in our patients.

Table 1 The parameters (mm) of mini-implants and breaking force of power chain.

	AbsoAnchors	Bioray	Lomas
Inner diameter	1.24	1.49	1.45
Outer diameter	1.94	1.92	1.98
Inner diameter/Outer diameter	0.64	0.78	0.73
Thread pitch	0.70	0.76	0.75
Thread depth	0.35	0.22	0.27

Average breaking force of power chain (21.9 Ncm)

Table 2 The mean insertion torque, pull-out strength and their standard deviations. (SD) in the vertical direction of the measurements (including $n = 5$).

	Insertion torque (Ncm)	Pull out strength (Ncm)	Correlation coefficient
Abso Anchors	6.2	109.72*	0.06
Bioray	8.62	133.14	−0.63
Lomas	10.82	139.68	0.06

*Statistical significance was set at $P < 0.05$.

The palatal bone thickness is very important for inserting orthodontic mini-implants. Gracco et al[15] used cone beam computed tomography to evaluate the thickness of the palatal bone, and found that the anterior palate, median suture, and paramedian areas have the thickest bone (>5 mm). They did not find significant differences between men and women or between the right and left sides of the palate. Considering that the palatal thickness determines the length of the mini-implant to be used, the thickness of the palatal mucosa cannot be ignored. Song et al[16] reported that the mean palatal mucosal thicknesses, according to the tooth site, were 3.46 (maxillary canine), 3.66 (first premolar), 3.81 (second premolar), 3.13 (first molar), 3.31 (base of the interproximal papilla of the first and second molars), and 3.39 mm (second molar). According to the results of previous research,[15,16] we used a 3-mm thick palatal mucosa and 5-mm thick (2-mm cortical bone) artificial bone (Sawbones) for this study. Therefore, the outcomes were more realistic and allow for accurate comparison with clinical situations.

The most common parameter used for quantifying the stability of mini-implants is the pullout strength. First, the size of the palatal implant must be chosen. The Straumann palatal implant has a 3.3-mm diameter, a 4- or 6-mm length, and a 2.5- or 4.5-mm transmucosal neck length. However, this implant requires a surgical flap operation for insertion and removal. Therefore, smaller sized and less-integrated mini-implants were developed to simplify the operative procedures. In an animal study, Salmória et al[17] analyzed the correlation between the insertion torque and pullout strength at 0, 15, and 60 days after mini-implant (1.6-mm diameter and 6.0-mm length) placement, but they found no correlation. Therefore, whether the insertion torque could be a predictor of pullout strength needed to tested *in vitro*. To accurately evaluate the insertion torque and pullout strength of the mini-implants, we used identical mechanical properties of artificial bone and the insertion technique for all mini-implants. However, we found no significant correlation between the insertion torque and pullout strength (vertical and horizontal directions). Therefore, our findings are in agreement with those of Salmória et al,[17] which imply that the insertion torque cannot reliably predict the pullout strength.

Table 3 The mean insertion torque, pull-out strength and their standard deviations (SD) in the horizontal direction of the measurements (including $n = 5$).

	Insertion torque (Ncm)		Pull-out strength (Ncm)		Correlation coefficient
	Mean	SD	Mean	SD	
Abso Anchors	5.9	0.54	171.62	5.5	0.12
Bioray	9.74	1.01	124.84*	14.54	0.01
Lomas	11.66	0.6	179.78	21.48	0.20

*Statistical significance was set at $P < 0.05$.

In our study, the mean vertical and horizontal pullout strengths were in the range of 109.72—139.68 and 124.84—179.78 N, respectively. Although there was no significant difference among the tested brands in terms of the vertical pullout strength, the Absoanchor mini-implants yielded the lowest value. This difference can be explained by the fact that the flutes of the Absoanchor mini-implants are hemi-trimmed at $\sim$2 mm from the apex; therefore, their insertion torque and vertical pullout strength were lower. When a horizontal pullout force was applied to these mini-implants, the insertion holes widened, resulting in loosening of the mini-implants. The horizontal pullout strength of the Bio-Ray mini-implants was significantly lower than those of the other brands, because the grip surface decreased with decreasing mini-implant thread depth and resulted in a lower pullout strength. The thread depth of the Bio-Ray mini-implants was smaller than those of the Lomas and Absoanchor mini-implants. Compared to the vertical pullout strength, the horizontal pullout strength was significantly greater for the Lomas and Absoanchor mini-implants than for the Bio-Ray mini-implant, but no significant difference was found between the pullout strengths of the Bio-Ray mini-implant. In this series of tests, the Lomas mini-implant exhibited greater stability and holding strength. However, the breaking force (21.9 N/cm) of the orthodontic power chains was much lower than the vertical and horizontal pullout strengths of any type of palatal mini-implant.

Conclusions

Stabilization of skeletal anchorage is necessary for orthodontic palatal treatment with mini-implants. In our study, the vertical pullout strength of the Absoanchor mini-implant was significantly lower than those of the other brands, and the horizontal pullout strengths of the Lomas and Absoanchor mini-implants were significantly higher than that of the Bio-Ray mini-implant. We suggest that additional criteria such as thread design should be considered when choosing a palatal mini-implant. Considering that our study involved *in vitro* experiments on artificial bone, the results should be interpreted and applied with great caution in the clinic.

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